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Changes in club head trajectory and planarity throughout the golf swing

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Abstract. This paper investigates the planarity and changes in club head trajectory throughout the golf swing. Four male, highly skilled golfers were captured hitting 40 shots using an optical motion capture system. Planes were fitted to four phases of the golf swing for comparison across the 40 shots in each player. While trajectory variability was seen to increase from takeaway to the top of the backswing, it then decreased again leading up to impact. The correlation between the delivery horizontal plane angle and the other planes decreased the further back through the swing the plane was situated. This finding suggests that although changes to the club head trajectory in the early part of the swing may have an effect in delivery to the ball, this effect is stronger the further through the swing the change is made. This paper describes the use of a novel method for quantifying changes in club head trajectory through the golf swing.

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1. Introduction

A successful performance of a golf swing has been described by coaches as “repeatable, controlled, simple, accurate, powerful and consistent” (Smith et al., 2012, p.228). Although there is a large body of biomechanical research into the golf swing, it appears that the directionality and consistency of the golf shot with respect to this technique has received less attention than the power (Keogh and Hume, 2012).

The initial direction and curvature of a golf shot, and therefore its likely finishing position, have been shown to be most strongly influenced by a combination of the path and orientation of the club as it impacts the ball (Sweeney et al., 2013). This agrees with the technique analysis strategies of two of the biggest Professional Golfers

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Associations in the world (Wiren, 1991; PGA, 2012). Although these coaching associations additionally suggest relationships between these impact conditions and swing technique there has been little empirical research backing this up.

As an element of technique that is primarily concerned with the trajectory of the club head during the swing, the swing plane may be useful in linking technique to performance. Recently Kwon et al. (2012) defined the 'functional swing plane' as the plane fitted to the trajectory of the clubhead from shaft horizontal pre- to post-impact. Using the horizontal orientation of this plane as a technique variable, a relationship can be seen to exist between this and the club path at impact depending on where in the arc of the clubhead the ball is struck. While this 'functional swing plane' was well defined by Kwon et al. (2012), its use in other parts of the swing and the strategies by which it is varied by players during the golf swing have not yet been investigated.

Investigating relationships between elements of technique and performance outcomes should be prioritised to assist coaches in making their decisions about altering technique. Plane fitting offers a method by which 3-dimensional trajectories can be compared, whilst also being relevant to golf coaches. Therefore, the aim of this study was to investigate how planes fitted to other phases of the swing vary and what correlation they have to the swing plane around impact.

2. Methods

2.1. Procedure

Four male golfers (mean \pm SD: age 24.8 \pm 4.5 yrs; mass 82.0 \pm 8.9kg; height 1.77 \pm 0.04m; handicap 2.0 \pm 2.6) hit 40 shots at a target on a fairway projected onto a net using their own driver. A minimum rest period of 60 seconds between shots was enforced to minimise fatigue, along with 5 minute breaks after every 8 shots. During the warm-up the players were asked to verbalise their desired trajectory for the shot and to attempt to repeat this trajectory for all trials, this was also reinforced during the breaks.

Club head kinematic data were collected using nine Oqus 300 cameras (Qualisys AB, Sweden) at 300Hz. Four retro-reflective markers were attached to the crown of the driver head and were used as a rigid cluster for tracking the clubhead throughout the swing. The face centre was located relative to this cluster using an additional marker for the static trial only. Two strips of retro-reflective tape were stuck to the top of the shaft near the grip and these were used to establish shaft angles during the swing for event calculation.

2.2. Data Analysis

Four separate planes were fitted to the trajectory of the club face centre for four phases of each swing (fig.1b). Firstly, the takeaway phase was defined as the initial movement of the club, up to the point where the club was horizontal (mid-backswing).

Two further planes were calculated for the late backswing and early downswing. The top of the backswing has previously been defined as the point at which the club changes its direction away from the ball in the backswing to toward the ball in the downswing (Hume et al., 2005). However, at this point the club is not only changing swing direction, but also the route by which the club travels back to the ball, as can be seen in figure 1. Therefore, the transition phase of the swing was removed from the calculation of both the late backswing and early downswing planes. This transition phase was defined similarly to Colman and Anderson (2007) by using a percentage of the maximum clubhead speed as a threshold. This study used 20% of the maximum club head speed as it was felt this eliminated the influence of the direction change on the plane calculation.

The late backswing phase was defined as the point where the club shaft was horizontal in the backswing (mid-backswing) to the start of the transition phase. The early downswing phase was defined as the end of the transition phase to the point where the club shaft was horizontal (mid-downswing). Lastly, the delivery phase was from mid-downswing to the frame prior to ball impact. While this differs from the functional swing plane used by Kwon et al. (2012) (mid-downswing to mid-followthrough), this was to avoid the influence of the clubhead deflection that occurs upon impact with the ball (Williams and Sih, 2002).

Least squares orthogonal distance fitting was then used to fit the club head trajectory to a plane for each of the 4 phases outlined for each swing. For each plane the maximum orthogonal distance of a trajectory point from that

plane and the RMS error were calculated to assess the planarity of the phase.

As per Coleman and Rankin (2005), the swing planes were then projected onto the xy and yz reference planes. The angles of these projections to the x-axis and y-axis represented the horizontal plane angle (HPA) and vertical plane angle (VPA) respectively, where the x-axis was parallel to the ball to target line and the z-axis was vertically up (fig. 1a). A positive HPA pointed to the right of the target, and the VPA increased as it approached vertical.

Variability in trajectory of the clubhead in 3-dimensions was calculated using a normalised variability volume method (Tucker et al., 2013). This technique involved normalising the time series to 1001 points with a cubic spline interpolation, and using three 20% sections of both the backswing and downswing before using Tucker's et al. (2013) method on these 6 sections. The data were interpolated for this analysis only; the plane fitting did not involve any interpolation of the data. The variability volume methods was chosen for its applicability to 3-dimensional trajectories and because it has already been used in golf swing analysis.

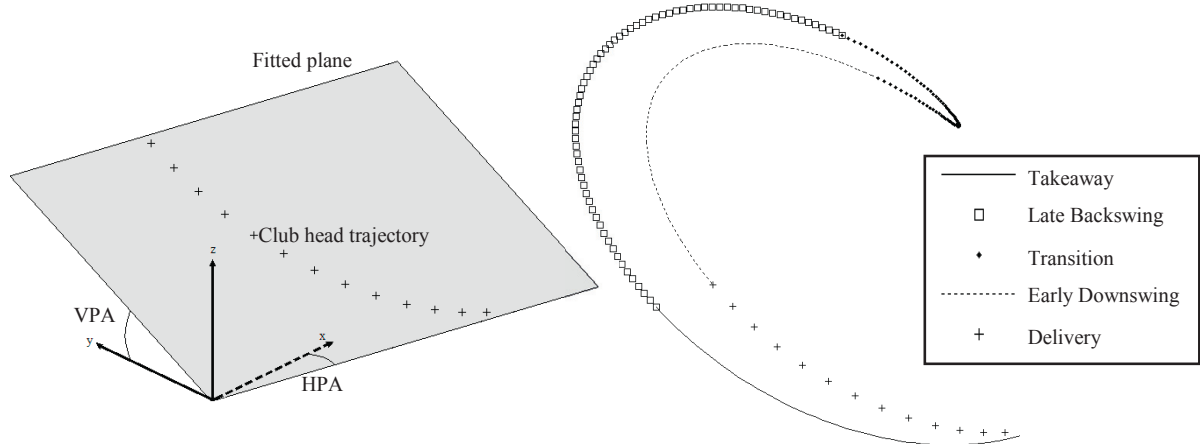


Fig 1.(a) Horizontal Plane Angle (HPA) and Vertical Plane Angle (VPA) of the plane fitted to the clubhead trajectory (left);
(b) Phases of the trajectory of the clubhead (right)

2.3. Statistical Analysis

The HPA and VPA were compared for all combinations of the takeaway, late backswing, early downswing and delivery planes using an ANOVA to assess if the planes were orientated at significantly different angles. Then the Pearson's correlation coefficients were calculated for the relationship between each of the four planes for each player. No comparisons were made between subjects as the players were allowed to use their own swing strategies and these were inevitably going to be different.

3. Results

3.1. Club Head Trajectory Variability

Across the four players the variability of the club head trajectory showed a general trend to increase over the course of the backswing (fig. 2a). During the downswing the variability tended to decrease across the group (fig. 2b).

3.2. Swing Planes

In all players the delivery phase appeared to fit to a plane with the least error, with the highest RMS error value at 1.28mm (± 0.26) (table 1). The highest RMS error value varied between the other three phases for the four players. The highest overall RMS error value was for player 2 in the takeaway phase (7.46mm ± 0.61).

The HPA for each swing phase were all significantly different from each other ($p < 0.05$) for players 2, 3 and 4. Player 1's delivery HPA was not significantly different from the takeaway HPA, and similarly the late backswing

and early downswing HPA were also not significantly different. The VPA for each swing phase were significantly different from each other for all players, except the early downswing and delivery plane for player 4.

The correlation between the delivery HPA and the other HPAs appeared to increase chronologically (i.e. the early downswing HPA was more highly correlated with the delivery HPA than the takeaway HPA) in all players (fig. 3).

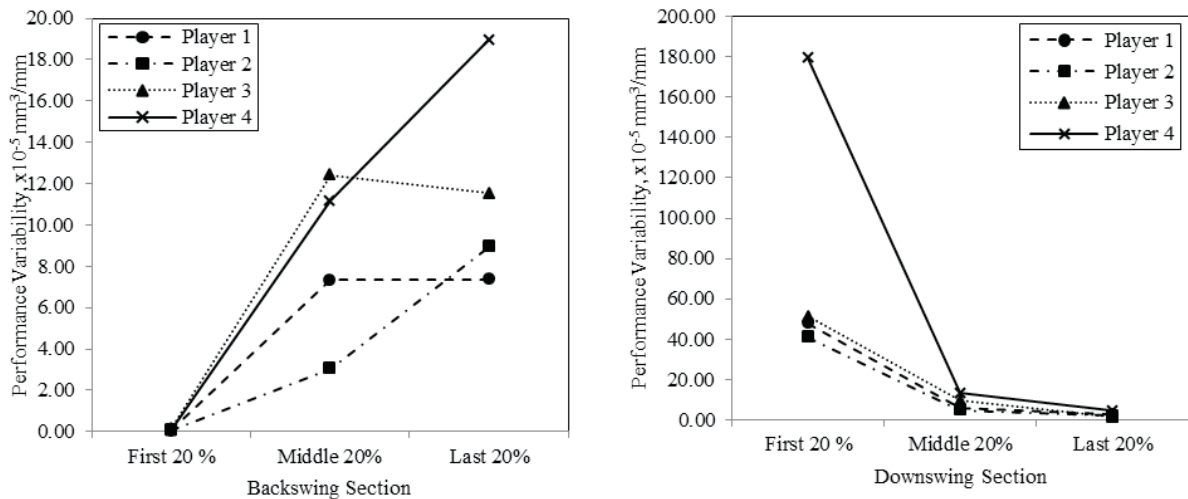


Fig. 2. (a) Variability club head trajectory for the sections of the backswing;
(b) Variability club head trajectory for the sections of the downswing

Table 1. Planarity of the clubhead trajectory and orientation of each plane

	Player 1 (Hcp +1)		Player 2 (Hcp 1)		Player 3 (Hcp3)		Player 4 (Hcp 5)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Delivery HPA (deg)	0.88 ± 1.06		1.25 ± 1.08		7.52 ± 1.15		11.94 ± 0.97	
Delivery VPA (deg)	46.52 ± 0.63		49.95 ± 0.53		44.58 ± 0.66		54.56 ± 0.66	
Maximum Error (mm)	1.13 ± 0.28		0.80 ± 0.27		1.29 ± 0.31		2.32 ± 0.45	
RMS Error (mm)	0.62 ± 0.16		0.43 ± 0.15		0.64 ± 0.16		1.28 ± 0.26	
Early Downswing HPA (deg)	4.31 ± 1.11		6.82 ± 1.14		10.08 ± 1.46		21.56 ± 1.27	
Early Downswing VPA (deg)	45.95 ± 0.66		48.26 ± 0.56		43.63 ± 0.74		54.29 ± 0.92	
Maximum Error (mm)	9.78 ± 1.10		15.35 ± 1.60		15.09 ± 1.91		6.11 ± 1.35	
RMS Error (mm)	4.13 ± 0.46		6.57 ± 0.64		5.96 ± 0.83		2.11 ± 0.59	
Late Backswing HPA (deg)	4.59 ± 1.22		10.89 ± 1.42		2.08 ± 1.26		20.97 ± 1.18	
Late Backswing VPA (deg)	51.66 ± 0.54		48.77 ± 0.70		46.14 ± 0.80		49.17 ± 0.59	
Maximum Error (mm)	3.28 ± 1.04		14.33 ± 1.51		13.89 ± 2.76		12.07 ± 2.25	
RMS Error (mm)	1.30 ± 0.33		5.56 ± 0.64		6.08 ± 1.24		4.69 ± 0.99	
Takeaway HPA (deg)	0.53 ± 1.15		2.45 ± 0.89		-4.55 ± 1.10		3.28 ± 1.05	
Takeaway VPA (deg)	48.84 ± 0.62		45.13 ± 0.57		45.38 ± 0.94		46.35 ± 0.60	
Maximum Error (mm)	9.02 ± 1.76		18.61 ± 1.77		6.04 ± 1.99		12.36 ± 2.04	
RMS Error (mm)	3.86 ± 0.71		7.46 ± 0.61		2.44 ± 0.94		4.19 ± 0.70	

Table 2. Pearson's correlation coefficients for the HPA of each phase (* significant correlation, $p < 0.05$)

Horizontal Plane Angles	Player 1		Player 2		Player 3		Player 4	
	r	sig	r	sig	r	sig	r	sig
Delivery vs Early Downswing	0.843	* 0.000	0.900	* 0.000	0.867	* 0.000	0.679	* 0.000
Delivery vs Late Backswing	0.440	* 0.004	0.584	* 0.000	0.272	* 0.045	0.419	* 0.004
Delivery vs Takeaway	0.263	0.060	0.485	* 0.001	0.136	0.201	0.287	* 0.036

Early Downswing vs Late Backswing	0.685	*	0.000	0.758	*	0.000	0.330	*	0.019	0.725	*	0.000
Early Downswing vs Takeaway	0.413	*	0.006	0.598	*	0.000	-0.022		0.445	0.536	*	0.000
Late Backswing vs Takeaway	0.765	*	0.000	0.793	*	0.000	0.263		0.051	0.700	*	0.000

4. Discussion

The variability of the trajectory of the club head decreases throughout the downswing. This finding agrees with the research suggesting a zeroing-in on the goal specific demands of the task both in golf (Horan et al., 2011; Koenig et al., 1994) and in other sporting movements (Bootsma and Van Wieringen, 1990; Scott et al., 1997; Lee et al., 1982). Conversely, the variability in the backswing club head trajectory increases from the setup position. As this setup up position and backswing movement is unique to golf, other sports studies have not addressed this phase. Those golf studies that have investigated movement variability have mainly focussed on the downswing; however, Koenig et al. (1994) investigated force production variability, including the backswing, and their findings agree with the finding of this study. This peak in variability around transition may be due to the low club head velocity at this point, or it may be an opportunity for functional adaptations to be made.

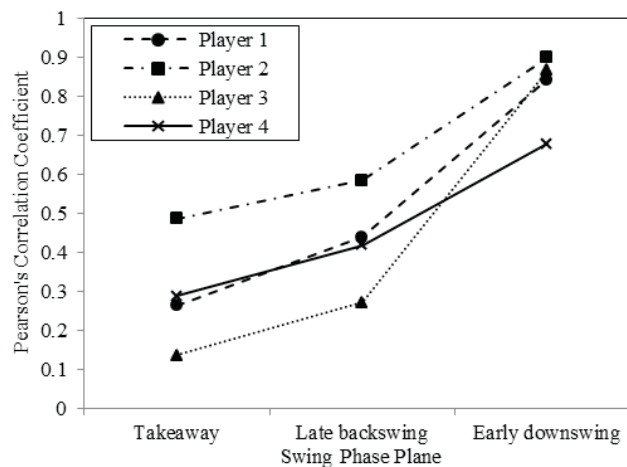


Figure 3. Correlations coefficients of the first three HPAs to the delivery HPA

As with the findings of Kwon et al. (2012), the phase of the club head trajectory near impact is highly planar. The lower RMS error values in this study compared to Kwon et al. (2012) may be attributed to the exclusion of the post impact club deflection. The high planarity of this phase may suggest that by the start of the delivery phase the overall direction the club head is travelling has already been determined, as little deviation occurs after this point. Although the values of RMS error in the other phases were higher they still appear to fit well to a plane. Similarly to the variability, the less planar phases may be due to the club travelling slower and be an opportunity for further, smaller adaptations to be made. However, further investigation should be directed at planarity as a method for measuring the simplicity of the swing that coaches suggest is important.

Although the orientations of the planes in each phase were different (table 1), there was evidence that plane angle changes between phases were correlated across the 40 swing performed by each player (table 2). However, increase in the correlation coefficient sequentially through the swing suggests that movement paths earlier in the swing have less influence on the final delivery phase. The implication for coaches may be that changes in early phases of the swing may have some effect on the club path at impact. However, as adaptations may occur throughout the swing, the strength of this effect increases the further through the swing the changes are made.

5. Conclusion

While it is commonplace for coaches to alter golf swing technique in setup and takeaway with the goal of affecting the shot outcome, it should be noted that the higher levels of variability in the backswing and low levels of correlation with the final delivery suggest that a greater tolerance should be allowed in the earlier phases of the swing. This study has sought to apply a previously used plane fitting method to the full swing and has provided a method by which changes in club trajectory can be compared during the swing and related to the pre-impact conditions that affect performance. Research is on-going with larger group sizes to examine if higher levels of variability at different phases of the swing influence outcome variability, if the strength of correlations between phases differs between skill levels, and whether this zeroing-in phenomena is only confined to higher skill levels.

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